WHITE WATER ASSOCIATES, INC.

An Ecological Landscape Study of Deer-Vehicle Collisions in Kent County, Michigan

Submitted to:
Kent County Road Commission
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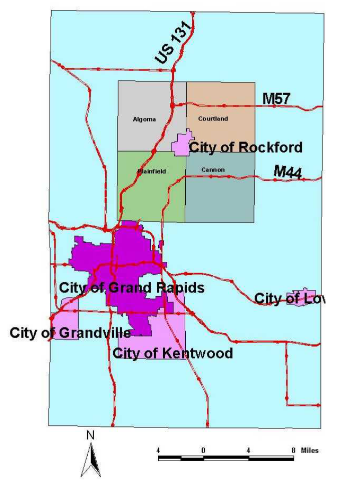

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Early guidance and inspiration for the project was provided by a multi-agency advisory committee that included personnel from Michigan Department of Transportation (MDOT), Michigan Department of Natural Resources – Wildlife Division (MDNR), Michigan State Police Office of Highway Safety Planning (MSP-OHSP), AAA Michigan – Community Safety Programs, and Federal Highway Administration (FHWA).

Mr. Kurt Thompson, Research Associate at the Annis Water Resources Institute (AWRI), Information Services Center, Grand Valley State University, Allendale, Michigan, and students from AWRI provided invaluable services geo-referencing the collision data for inclusion in the Kent County Road Commission's GIS project. The baseline KCRC geographical information system (GIS) project with roads, land use, and geographical features was also designed and built by Mr. Thompson and students from AWRI.

The funder and interested parties are thanked for their patience during the long process of this multi-year, collaborative study.

keywords
deer-vehicle collisions, DVC, ecological landscape, white-tailed deer, GIS, highway safety

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EXECUTIVE SUMMARY

American landscapes, once primarily rural and agricultural, are more and more urban to suburban in nature, with concomitant increases in roads and traffic and fragmentation of intact blocks of deer habitat. At the same time, deer populations in many areas are on the rise in response to the perpetuation of good habitat in a human-modified landscape, often combined with decreased hunting pressure. These factors have created an inherent deer-human conflict that is manifest in rising numbers of deer-vehicle collisions or DVCs.

Kent County, Michigan exemplifies this human-wildlife conflict, reporting the highest number of white-tailed deer–vehicle collisions of any county in Michigan for several years running. In 2001 alone, 2327 DVCs were reported in Kent County, accounting for 3.5% of the Michigan total. Confronted with the dilemma of high numbers of deer-vehicle collisions and their associated costs, and presented with an opportunity for a landscape analysis provided by an existing geographical information system (GIS), the Michigan State Police and Kent County Road Commission undertook a multi-year study of patterns of deer-vehicle collisions (DVCs). Using the existing GIS project, researchers undertook an analysis of landscape patterns of DVCs. The project also included a multi-year experimental application of novel seasonal deer collision warning signs on selected stretches of road and a multi-year trial of wildlife warning reflectors on other stretches of road.

In this study, neither the warning signs nor the wildlife reflectors showed any effect of reducing DVCs on the study roads. There may be situations or landscapes where these techniques can be effective, but in this particular landscape mixture of development and agriculture the results were not promising, and certainly not cost effective.

Analysis of landscape patterns in this study showed that the probability of experiencing a deer-vehicle collision is higher on roads that pass near watercourses and on roads that traverse a patchwork of many land use types. Risk of DVCs is lower in areas with large intact blocks of land suitable as deer habitat. Temporal analysis revealed a fall/early winter peak in numbers of DVCs, the same as reported in other studies. During the 24 hour day, drivers face the greatest risk of collisions in early morning and evening to midnight hours. All these types of information can be used in public awareness and driver education campaigns.

The spatial and temporal data that were part of this study's GIS project are invaluable tools for deciding future management actions. Keeping a current GIS project with locations of DVCs, and perhaps developing other landscape themes such as natural areas and parks, areas of current or projected development, and spatially-specific deer population counts, are investments likely to pay off in the future.

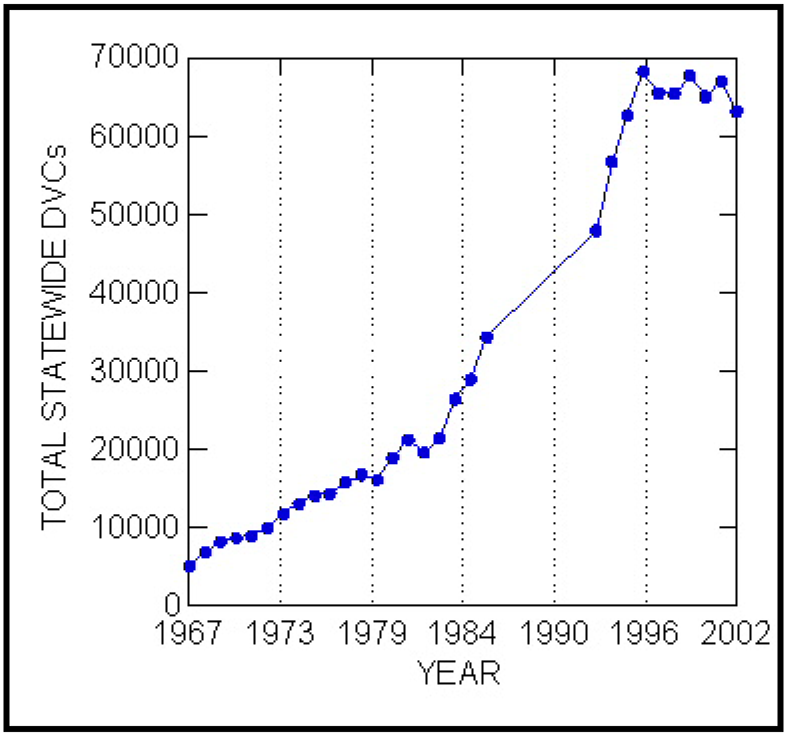
TABLE OF CONTENTS

SECTION I. INTRODUCTION

Deer-vehicle collisions (DVCs) are a growing problem throughout much North America. DVCs typically increase as deer populations rise on landscapes that are simultaneously experiencing a growing human population that leads to escalation of miles of road and volume of vehicular traffic (McShea et al. 1997). There are no simple, unambiguous relationships between deer populations, traffic patterns, land uses, and DVCs (Bruinderink and Hazebroek 1996) but their interactions undoubtedly account for the widespread increase in DVCs on a variety of landscapes.

In Michigan, the number of DVCs (involving white-tailed deer, *Odocoileus virginiana*) has steadily increased over the past two decades with 19,614 reported in 1982, 42,494 in 1992 and 63,136 in 2002 (Michigan Deer Crash Coalition 2003 and Michigan Department of Natural Resources 1987). The statewide trend has been one of a continual increase in numbers of DVCs since 1968 until 1996 when a fluctuating trend of high DVCs began (Figure 1).

Figure 1
Statewide Reported DVC Totals By Year
(data from Michigan Deer Crash Coalition 2003 and Michigan Department of Natural Resources 1987)



In human-modified suburban landscapes, deer find suitable to ideal habitat that offers abundant food and cover, and often, decreased hunting pressure. A variety of studies have examined patterns of DVCs in diverse types of landscapes (e.g. Allen and McCullough 1976, Bashore et al. 1985, Finder et al. 1999, Hubbard et al. 2000, McCaffery 1973, Puglisi et al. 1974, Schwabe et al. 2000). This study contributes to the existing body of knowledge.

Kent County, Michigan, exemplifies deer-human-vehicle conflict. This county contains the second largest city in Michigan, Grand Rapids (population of nearly 200,000 in the year 2000 with a greater metro region of about a million people). In the past decade, the population of Grand Rapids has grown 4%. Increasing residential development into what was once a primarily agricultural landscape has fragmented large blocks of crop and orchard land, while still leaving available significant amounts of deer habitat. At the same time, the volume of traffic has increased as more commuters move between residences and the city. With development has come a decrease in deer hunting, in part due to access to hunting lands creating a prescription for larger local deer populations whenever habitat and environmental conditions are favorable. All these factors have worked synergistically to give Kent County the highest number of DVCs in Michigan for several years running, most recently in 2001. The 2327 DVCs reported in 2001 represent 3.5% of the total DVCs reported in Michigan in that year.

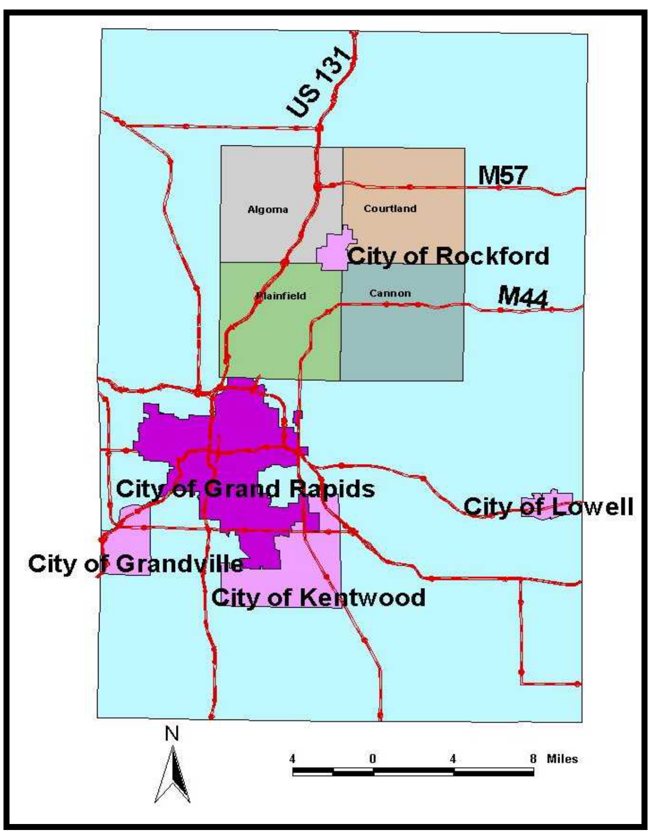
Faced with the dilemma of high numbers of deer-vehicle collisions and their associated costs, and presented with an opportunity for a landscape analysis of DVCs provided by an existing geographical information system (GIS), the Michigan State Police and Kent County Road Commission undertook a multi-year study of patterns of deer-vehicle collisions (DVCs) on its landscape. The project also included an experimental test of two potential mitigative techniques selected from a literature review (Premo and Premo 1995).

This report focuses on landscape patterns of deer-vehicle collisions in four townships of Kent County, Michigan. It also includes results from the experimental application of two mitigative techniques, motorist warning signs and wildlife reflectors. It is organized into 6 sections: Section I, Introduction (this section), Section II, Description of Project Area, Section III,, Methods, Section IV, Results, Section V, Discussion, and Section VI, Conclusions. References cited are provided at the end of the document.

SECTION II. DESCRIPTION OF PROJECT AREA

Four contiguous townships, lying north of the City of Grand Rapids, were selected for the study (Figure 2). These townships possessed similar attributes in terms of roads, human residential population, proximity to urban areas, types of land uses, and incidence of deer-vehicle collisions (DVCs). In addition, the townships' mixture of cultural and natural features was representative of much of Kent County. This four township project area has experienced rapid growth in development with increasing areas of formerly intact agricultural land subdivided into rural residences on small acre parcels. The City of Rockford, population 4626, is centrally located in the project area. This municipality's population has increased 23.4% in a 10 year period (1990-2000), illustrating the influx of people into what was once a primarily rural landscape.

Figure 2
Location of Project Area in Kent County, Michigan



Prior to the study, Kent County Road Commission had compiled a countywide geographic information system (GIS) database in collaboration with the Annis Water Resources Institute at Grand Valley State University, primarily for road maintenance issues in Kent County. This database included spatial layers drawn from MiRIS[1] Base Maps and Land Cover Maps.

On the land cover map layer, each land cover category (52 categories statewide) was depicted with a polygon and identified by code. This format allowed for easy simplification, consolidation, and renaming of the land use categories as appropriate for various analyses. The base map layers included digitized shape files that included features such as political boundaries, land survey section lines, transportation (streets, two-lane paved roads, four-lane highways, railroads), watercourses (rivers, streams, and drains) and lakes, and major vegetative cover types. . Major state and federal roads and numerous rivers, streams, and drains cross the study landscape. (Figure 3).

Vegetative types included pasture, crops, orchards, coniferous and deciduous woods, and aquatic and open wetland. Development categories included high and low density residential, commercial, and parks. The categories depicted in Figure 4 were consolidated from the original base cover file and were used for most of the analyses. Upon closer inspection, it was apparent that the category "parks" referred to recreational areas such as golf courses, not natural area parks that primarily provide green space. Rather, nature parks were classified by their vegetative cover type.

[1] MIRIS, Michigan Resource Information System Base Maps are digitized from USGS quadrangles and maintained by the Michigan Department of Natural Resources" (MDNR) Michigan Resource Inventory Program (MRIP). Coordinate positions are based on the North American Datum of 1927. Land Cover Maps are derived from 1:24000 scale color infrared and black-and-white aerial photographs, 1978.

Figure 3
Major Transportation and Stream Features of Project Area

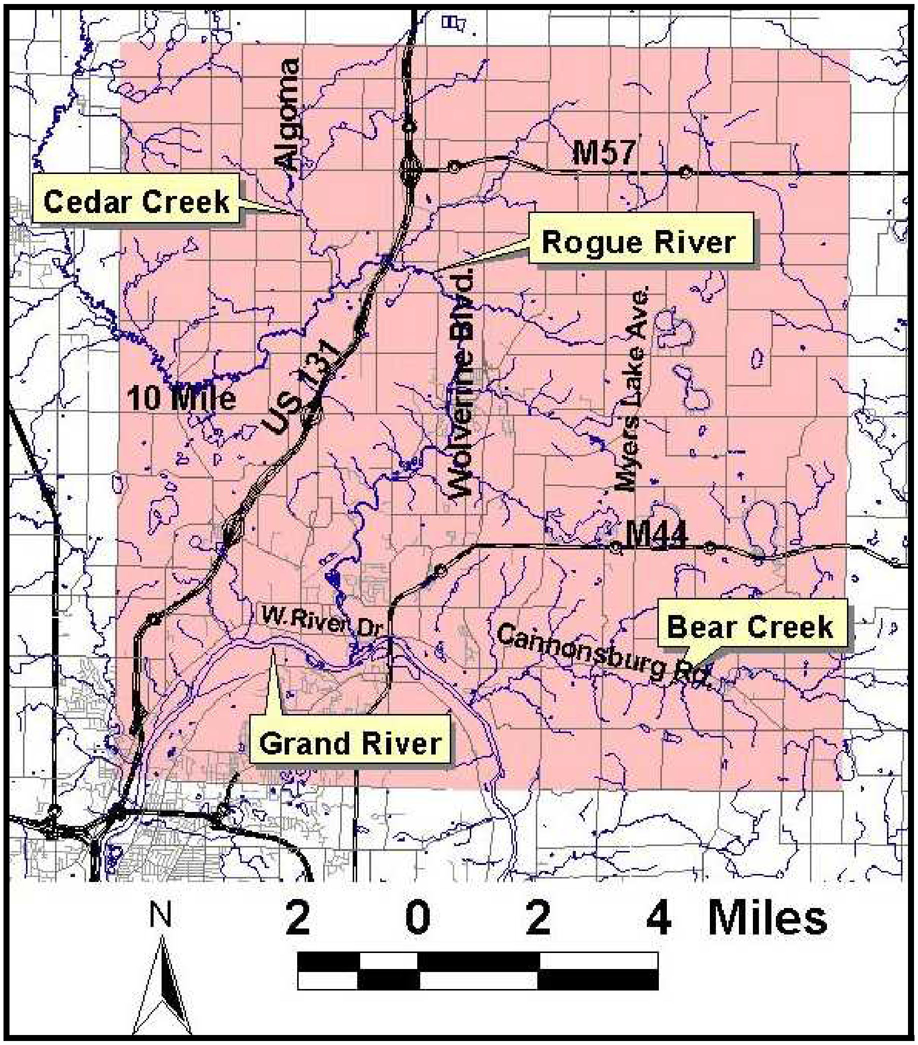
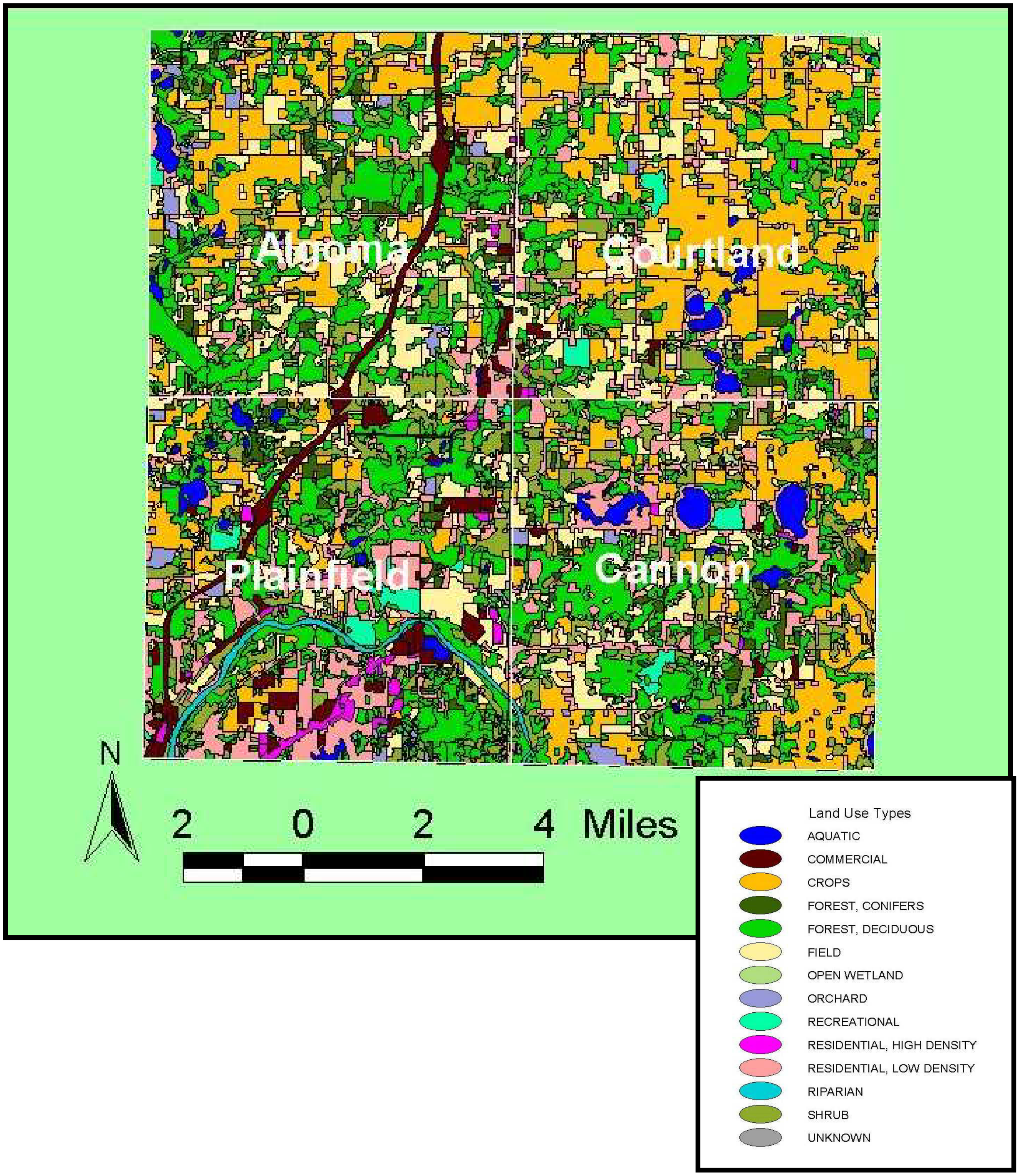


Figure 4

Study Landscape with Land Use Types



Finally, locations of deer-vehicle collisions (DVCs) were secured from the Michigan Accident Location Index (MALI) maintained by the Michigan State Police (MSP) for the years 1992-2000. MALI uses a system of unique physical reference numbers to spatially record accidents on roads throughout the State. Locations are based on police reports. Data from the four study townships were then geo-referenced and mapped on the Kent County geographical information system by Mr. Kurt Thompson (Research Associate at the Annis Water Resources Institute at Grand Valley State University, Allendale, Michigan) and students at the Institute.

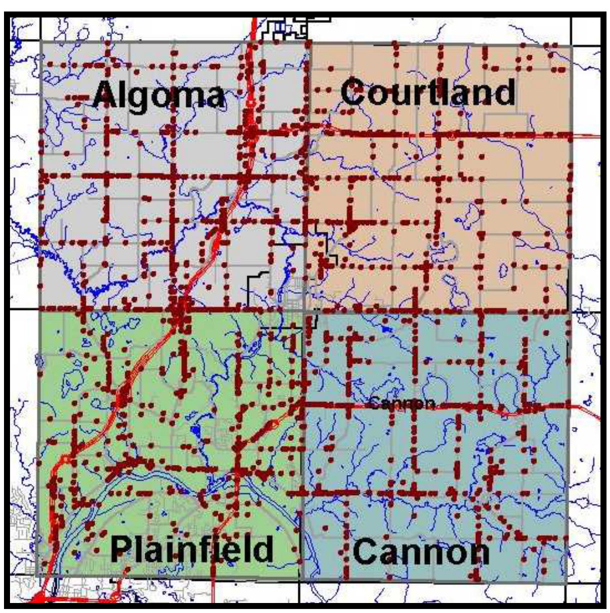
SECTION III: METHODS

DVC Data

Structures of data tables received from the Michigan State Police's MALI database differed from year to year. Before commencing any analysis, relevant fields common to all years were identified for retention (e.g. location, time, date) and field names were standardized. This allowed a compilation of all years into one data table of DVCs. Other useful codes (e.g. month, year, treatment period) were added to the table. This set was further refined by using geo-processing tools to assign a township field to each collision record creating a master data set of 3127 DVC records cumulated over 9 years and coded by township, year, month, and time of day. This data set formed the basis for creating data subsets (such as by particular stretches of road or a study landscape sample grid) that were used for quantitative analysis.

A map of raw DVC data points (cumulative or by year) was produced (e.g. Figure 5) but the sheer numbers of points, the many points overlapping in location, and the linear arrangement of the DVCs along roads, precluded any simple visual analysis of DVCs on the landscape.

Figure 5
Map of Cumulative DVCs (9 years) on Project Area



Education

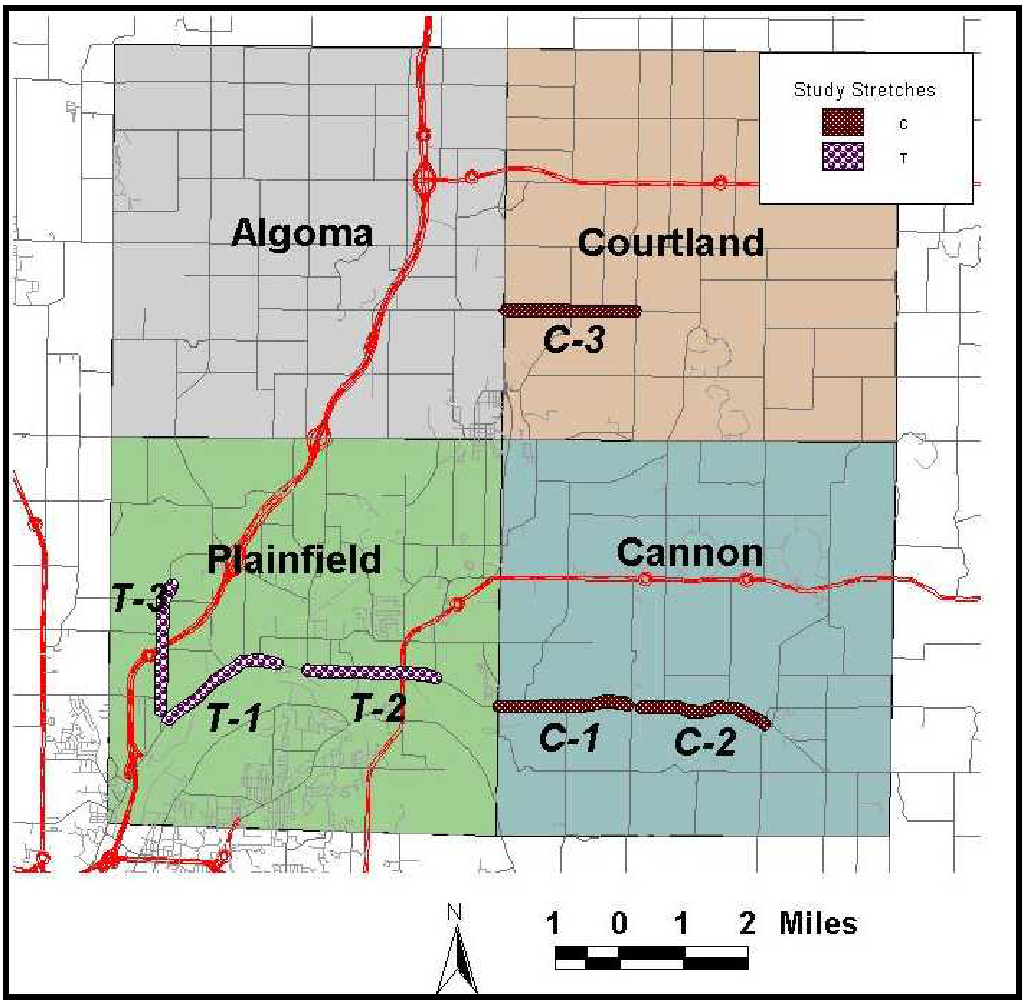
Education about the prevalence of deer-vehicle collisions and means of avoiding them took several forms. Most direct was a targeted campaign in 1998 to provide information about DVCs to driver education programs in Kent County using printed material and a video from the Michigan Car-Deer Crash Coalition of AAA of Michigan. Also in 1998, packets of information were distributed to township managers in Kent County. Finally, press releases regarding DVCs in Kent County and the ongoing study were provided to local radio, television, and newspapers. Instructors from 7 schools responded to a questionnaire about the usefulness of the materials they received.

Wildlife Warning Reflectors

Swareflex wildlife warning reflectors are based on technology introduced by Swarovski AG. The premise of such reflectors is that, properly installed and spaced, they will reflect vehicle headlights to create a low-intensity moving beam of red light that serves as a deterrent to animal movement while it is present, without interfering with driver vision. Strieter Corporation, the exclusive distributor and importer of Swareflex Reflectors for the United States and Canada, introduced a model called Strieter-Lite designed to allow for a simplified spacing of reflectors on varied terrain. This was the model of reflector used in this study.

Six two-mile stretches of road were selected from areas of high DVCs, as determined from data from 1992-1996. Three of these were designated as control stretches and three as treatment stretches. There was some hope that these stretches, matched by DVCs per million vehicle miles driven, could be used as paired control and test samples. As the study progressed, it became clear that the variability of landscape contexts and likely lack of independence in traffic patterns precluded this design. Instead, the control stretches provided a comparative way to identify influences of time or location on study outcomes. Reflectors were installed in 1998 along three stretches of road, T-1, T-2, and T-3 (Figure 6). These comprised the test stretches. Control stretches were labeled as C-1, C-2, and C-3. The Strieter-Lite Wild Animal Warning Reflector system was installed along the test stretches, with on site inspection by John Strieter in fall 1998 prior to the high collision period beginning in October.

Figure 6
Wildlife Reflector Experimental Stretches



Road Warning Sign Tests

Two types of warning signs were installed in Algoma Township. These included 52 regular signs (leaping deer on standard orange background) deployed throughout the township, and 18 novel signs deployed on 7 specific road stretches. Using DVC data from 1992-1996, 7 stretches of road (for a total of approximately 35 miles of roadway) were identified in Algoma Township that accounted for a majority of the accidents in the township. These stretches were selected for the deployment of the novel deer collision warning signs. Figure 7 shows approximate road stretches where vehicle speeds could be potentially affected by the novel warning signs (Figure 8).

Figure 7
Road Stretches with Novel Warning Signs In Algoma Township

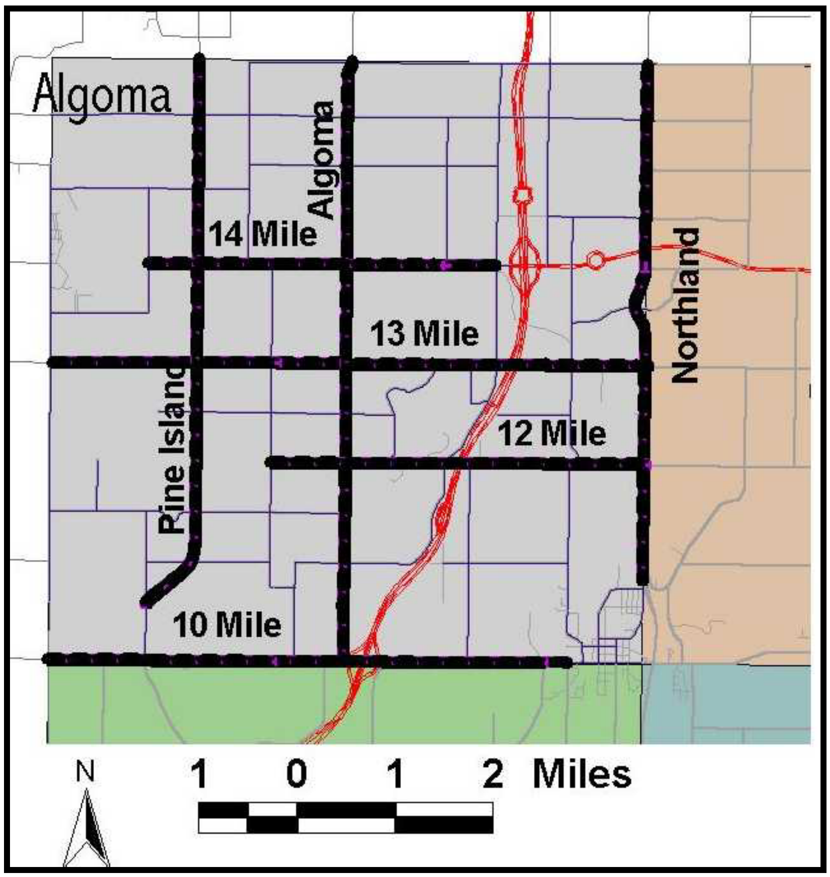


Figure 8
Novel Deer Collision Warning Sign

Signs were deployed on October 1 and removed on January 1, for three years, 1998, 1999, and 2000. This deployment period encompassed the seasonal peak period of DVCs. There were no warning signs on the landscape prior to this study and there are none on the landscape currently.

In 2000, traffic and speed recording devices were deployed before warning signs were installed for 24 hour periods on 5 road stretches (Algoma, Northland – north and south of 11 Mile, Pine Island, 10 Mile, and 13 Mile). Speed and traffic count data from after sign deployment were recovered for similar time periods (15 to 24 hours) for all stretches except Pine Island.

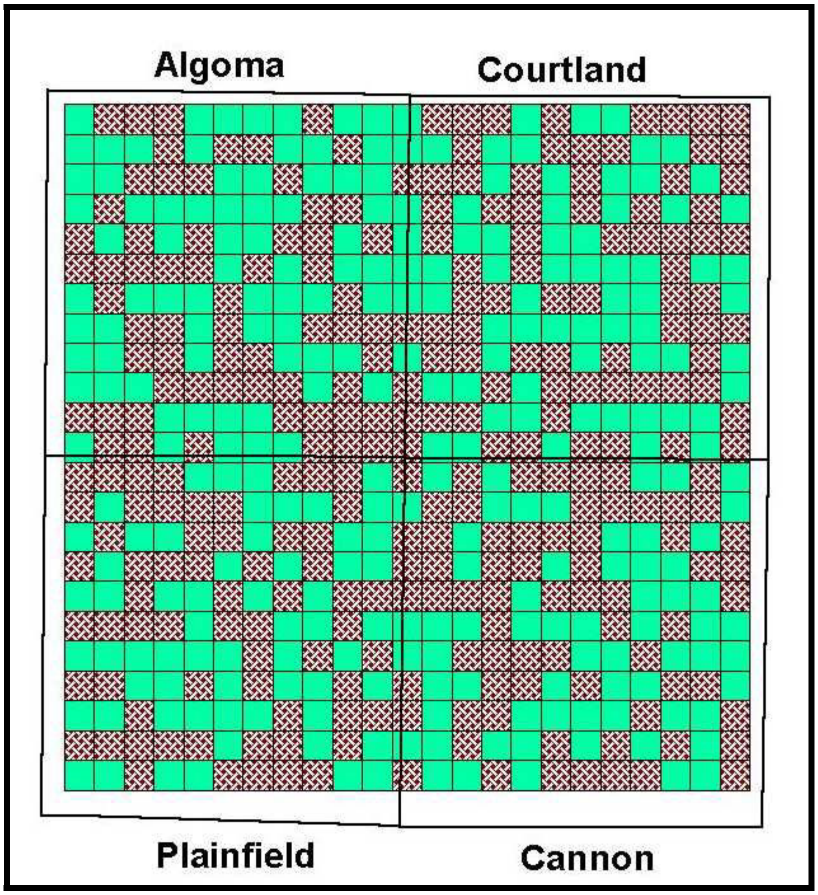
Landscape Patterns

Quantitative

Quantitative analysis of patterns of DVCs, acres of land use types, and geographical features was accomplished by creating and numbering a sample grid of half mile squares using an Avenue script in ArcView 3.2®. This grid was superimposed as a shapefile on the project area (Figure 9). It allowed for a summarization of landscape data that was independent of the linearity of the roads. It also made it possible to assemble summary statistics on roads and density of DVCs into a data set that also included areas of land uses as separate variables. Approaches using ArcView 3.2® to create polygon buffers of individual DVCs and summarize land use within a specified distance from each collision were deemed not practical given the high number of overlapping data points and the low precision in DVC location inherent in the driver-reported State Police MALI system. A half mile grid was chosen as being small enough to capture variation on the landscape while still being large enough to nullify any imprecision in DVC location.

A random number generator was used to randomly split the grid into two equally sized groups of cells. One half was used to generate a predictive model and the other half was employed to validate the model. Only whole grid cells were used in the analysis to eliminate both the need for standardization by sample area and problems created by DVC records lying along the border of the project area.

Figure 9
Sample Grid Divided Into Two Random Samples (Sample A, cross-hatched, Sample B, solid)



Visual

Visual inspection of DVC patterns was accomplished by using the density function in the Spatial Analyst® extension of ArcView 3.2® to distribute the measured quantity of an input theme (DVC points) throughout the landscape to produce a continuous surface. In this procedure, density is calculated for each cell in the GIS project by summing the number of DVCs found within the search radius (in this case, one-half mile) and dividing by the area of the search circle. This continuous surface was then used to create a contour line shapefile corresponding to DVC density that was examined for visual patterns with respect to the landscape.

Analysis Procedures

Data were analyzed primarily using ArcView 3.2® and SYSTAT 10® for data processing, summarization, and transformations. SYSTAT 10® and Sigma Plot® were used for statistical testing and graphing. Significance was set at alpha (α) =0.05 unless otherwise noted. Data were examined for normal distributions using probability plots. Residuals were examined for heteroscedasticity to determine whether variances were constant and further assess whether linear models were appropriate. For data sets with non-normal distribution or non-constant variances, non-parametric tests were applied wherever possible.

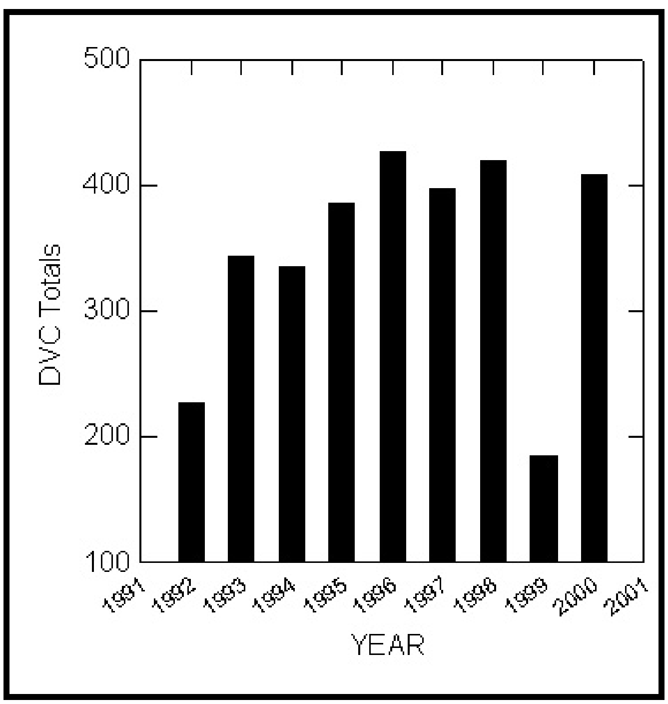
SECTION IV: RESULTS

Temporal Patterns

Yearly

There were significant differences among years 1992-2000 (compared across monthly totals) in numbers of DVCs (Kruskal-Wallis test statistic = 15.97, df=8, p=0.043) (Figure 10). The non-parametric Kruskal-Wallis test using ranked sums was used instead of a linear model. The presence of heteroscedastic residuals indicated that the variances were not constant and thus the assumptions of a linear model were violated. The year 1999 had the lowest number of DVCs in the project area, although the differences among years remained if data from 1999 were excluded and even if data from the two lowest years, 1999 and 1992 were excluded. Clearly, there is high variability among years in numbers of DVCs.

FIGURE 10
Total DVC Counts by Year (1992-2000)



Seasons

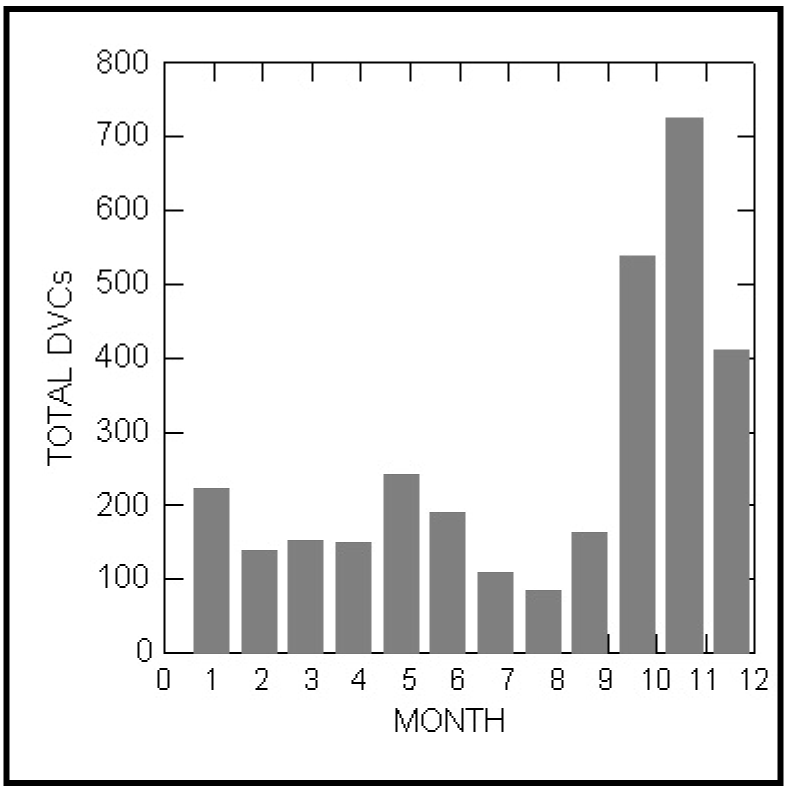
Summing over 9 years, the numbers of DVCs varied greatly among months (Kruskal-Wallis test statistic = 73.198, df=11, p<0.0001). Again, a non-parametric test was used instead of a linear model because of heteroscedastic residuals indicated variances that were not constant. The greatest numbers of collisions occurred in October, November and December. A one-way contingency table was constructed in SYSTAT® DVCs (out of total 3124 DVCs coded by month over 9 years) with percentages and 95% confidence intervals computed for each month (Figure 11). The confidence intervals were calculated in the SYSTAT® crosstabulation module and were based on an approximation (attributed in SYSTAT 2000 to Bailey 1980) that performs well for non-normal distributions. These were scaled as percentages for comparative purposes.

FIGURE 11
Percentages of DVCs and 95% Confidence Intervals by Month

MONTH	PERCENT OF TOTAL	CONFIDENCE INTERVAL	
		UPPER LIMIT	LOWER LIMIT
JAN	7.17	8.57	5.90
FEB	4.48	5.63	3.48
MAR	4.87	6.05	3.82
APR	4.80	5.98	3.76
MAY	7.71	9.161	6.394
JUN	6.11	7.43	4.94
JUL	3.46	4.48	2.58
AUG	2.68	3.61	1.92
SEP	5.21	6.44	4.13
OCT	17.22	19.22	15.32
NOV	23.18	25.39	21.03
DEC	13.09	14.89	11.40

The three peak months differ from each other with November being the highest. The three peak months combined account for 54% of the total number of DVCs throughout the study period (1992-2000). January, May and June accounted for similar percentages of total DVCs to each other, but were considerably less than the fall months. Likewise, February, March, and April were similar to each other. July and August accounted for the lowest percentages of DVCs. This pattern also can be seen on a bar graph of the raw DVC counts (Figure 12).

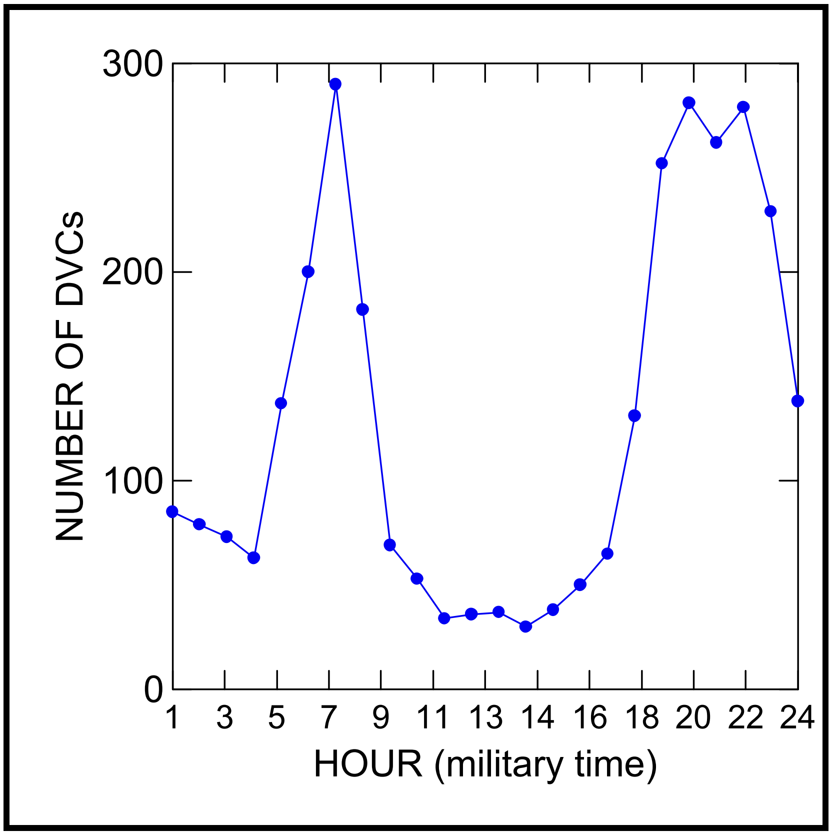
Figure 12
Total Numbers of DVCs by Month



Time of Day

Other DVC studies (e.g. Allen and McCullough 1976) have reported peak periods falling at dawn and dusk, postulated as corresponding to the crepuscular habits of deer (Kammermeyer and Marchinton 1977). One of this study's peaks fell at dawn and early morning. The evening peak collision period, however, continued through the night hours, only decreasing after midnight (Figure 13). This might be a result of traffic patterns or deer movement patterns, or a combination of factors. This temporal pattern may be peculiar to a suburban landscape such as the project area.

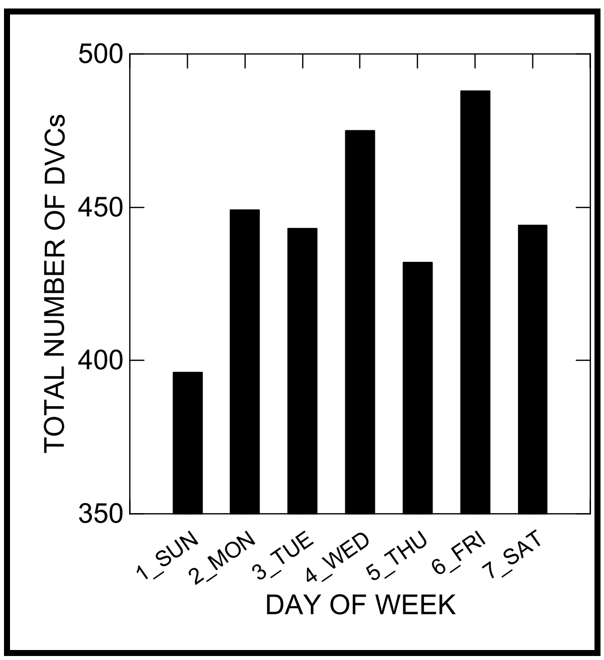
FIGURE 13
Number of DVCs by Time of Day



Day of Week

There were no significant differences in numbers of collisions among the days of the week at α=0.05 level, although there was a significant difference at α = 0.10 level (Pearson χ^2=11.0908, df=6, p=0.064) (Figure 14). This is in contrast to a study in southern Michigan that found weekend evenings to have a higher number of accidents, with the hypothesis that this was due to heavier traffic patterns (Allen and McCullough 1976). If Sunday (the day with the lowest number of collisions in this study) was excluded from this data set, no differences remained (Pearson χ^2=5.094, df=5, p=0.404).

FIGURE 14
Total Numbers of DVCs by Day of the Week



Driver Education and Public Awareness

Driver education teachers were very pleased to have simple statistics to provide to the students. With respect to the video, they were unanimous in their opinions that it was too long with a presentation style that was not interesting to the students. Even those who showed the video did not intend to do so again. One respondent suggested that a much shorter video (5 to 10 minutes) would be more useful to them, given the time constraints of their classes. They appreciated having information on the occurrence and hazards of DVCs provided to them for class presentation and especially liked the local information.

Experimental Studies

Wildlife Reflector Study

Standardized selection of DVC data for the reflector study from the GIS project was accomplished by creating a polyline theme for each of the 6 experimental stretches and buffering each of those lines by 500 feet on each side. This polygon shape theme was used to select DVCs and link them to the appropriate stretches by name. A buffer of five hundred feet from the center line was chosen so as to include DVCs most likely to be influenced by the reflectors and to take into account spatial discrepancies in plotted DVC locations relative to the line theme that represented roads. No other record of DVCs on the experimental stretches was available. A total of 279 DVCs were included in this data set. The year 1999 had a significantly lower number of collisions throughout the project area (see Section IV) and by chance none of these collisions occurred on any of the control or test stretches. Because both control and test stretches lacked DVCs in 1999, data from this year was considered to be statistical outlier. These data were not used in tests that examined the effects of reflectors so as to avoid the danger of drawing erroneous conclusions about the efficacy of experimental treatments.

Figure 15
Numbers of DVCs by Reflector Stretches and Year (500 foot buffer polygon)

YEAR

Stretch	1992	1993	1994	1995	1996	1997	1998	1999	2000	total
C-1	6	9	10	6	12	9	13	0	12	77
C-2	2	6	4	3	7	3	5	0	8	38
C-3	1	1	9	4	6	7	6	0	2	36
T-1	1	11	5	5	7	7	5	0	5	46
T-2	9	2	7	8	6	5	8	0	3	48
T-3	2	4	4	5	5	6	3	0	5	34
total	21	33	39	31	43	37	40	0	35	279

(C=Control, T=Test)

(Shaded cells are from period after reflectors were installed on test stretches)

Data from 1992-1997 were coded as BEFORE treatment and data from 1998 and 2000 were coded as AFTER treatment. Data were examined for a normal distribution using a probability plot and were found to approximate a normal distribution.

A two-way least squares ANOVA was run using a non-orthogonal data set consisting of two time periods: BEFORE (6 years) and AFTER (2 years). Each stretch was considered as an independent sample. Number of DVCs was the dependent variable, and time period and treatment stretch were the categorical variables. There was a significant effect of treatment stretch (F=5.44, df=5, p=0.0008). There was no effect of time period (F=0.4985, df=1, p=0.485), and no effect of the interaction of treatment stretch and time period (F=0.981, df=5, p=0.442). This indicates that there was no effect of the reflector treatment. An examination of residuals using a scatterplot showed homogeneity of variances and a stem and leaf plot of residuals revealed no outliers.

Differences among treatment stretches were examined through a one-way ANOVA followed by a post hoc Tukey HSD multiple comparison of probabilities. Through this analysis, it was found that control stretch C-1 had more DVCs than all the other stretches and accounted for the statistical difference among stretches. When this stretch was removed from the data set and the test repeated, no statistical differences remained.

There remained a conceptual design question of whether the treatment stretches could or should have been considered as independent samples. Some of the stretches are contiguous or nearly contiguous (C-1 and C-2 and T-1 and T-2) to one another and likely share traffic patterns. They also may lie within the home ranges of some of the same deer. Because of these issues, another two-way ANOVA was performed after lumping the stretches into two treatment categories, C (control) and T (test) and testing these against the two time periods of BEFORE and AFTER. There were no significant differences between C and T stretches ($F=2.577$, $df=1$, $p=0.116$), BEFORE and AFTER time periods ($df=1$, $F=0.350$, $p=0.557$), and no significant interactions between treatment and time period ($F=1.606$, $df=1$, $p=0.212$).

Reflectors would only be effective during night hours. To make certain that the results were not being confounded by collisions occurring at other times of day, analyses were repeated using DVCs occurring only during the peak collision hours of 1800 to 2400 hours, grouped by sample treatment, C and T (Figure 16). A two-way ANOVA was performed with number of DVCs as the dependent variable, and time period (BEFORE, AFTER) and sample treatment (C, T) as the categorical variables. As in the analysis using the full set of DVC data, the year 1999 was not included in this analysis. There were no significant effects of sample treatment ($F=1.43$, $df=1$, $p=0.256$), time period ($F=0.615593$, $df=1$, $p=0.448$), or the interaction term ($F=0.42$, $df=1$, $p=0.529$).

Figure 16
Numbers of DVCs in Peak Period (1800-2400 hr.) by Sample Treatment and Year

YEAR

Treatment	1992	1993	1994	1995	1996	1997	1998	1999	2000	total
C	3	9	16	5	16	8	15	0	11	83
T	6	12	11	8	4	8	11	0	6	66
Total	9	21	27	13	20	16	26	0	17	149

(C=Control, T=Test)

(Shaded cells are from period after reflectors were installed on test stretches)

Just in case the 500-foot sample polygons included DVCs that fell outside the potential influence of the reflectors, the analysis was repeated on DVC records from a more restricted 200 foot polygon, night records only, excluding 1999 from consideration. When the two year pre-trial (1996, 1997) and two year trial (1998, 2000) periods were compared for the test and control stretch groups, no differences were detected (χ^2=0.222, df=1, p=0.638). There were 11 DVCs recorded on the three test stretches in the pre-trial period and 14 recorded after reflectors were installed.

Deer Warning Signs

The effect of warning signs was examined by comparing number of DVCs during the sign deployment period (October, November, December, 1998, 1999, and 2000) with the period before sign deployment. The residuals of this data set exhibited heteroscedasticity, indicative of non-constant variances that precluded use of a linear model such as ANOVA.

The first step taken in this analysis was comparison of DVCs by year and township for the peak collision months (October, November, December) (Figure 17) using an r x c contingency table and a Pearson Chi-square (χ^2) test statistic. If the signs were effective in Algoma Township, one would expect Algoma to show a significantly lower number of DVCs in the period after sign deployment.

Figure 17
Number of DVCs for Sign Deployment Period* By Year and Township

	TOWNSHIP				
YEAR	**ALGOMA**	**CANNON**	**COURTLAND**	**PLAINFIELD**	**TOTAL**
1992	43	35	21	39	138
1993	65	53	23	55	196
1994	65	44	35	48	192
1995	67	47	37	62	213
1996	75	69	41	51	236
1997	62	54	30	66	212
1998	55	79	44	49	227
1999	22	33	24	16	95
2000	55	45	37	52	189
TOTAL	509	459	292	438	1698

** Deployment period was during the peak DVC season of October, November, December. Shaded boxes show years and township of sign deployment.*

There was a significant difference among years and townships (χ^2=38.12, df=24, p=0.034). This difference disappears, however, if the data from 1999 are removed. Since DVC counts were significantly lower in 1999 than the previous year for all four townships (including the three without warning signs), it was reasonable to treat the data from 1999 as an outlier and remove that year's data from the datasheet used to test the effect of warning signs. This procedure was consistent with the approach taken for the reflector analysis. For the test township, Algoma, the period two years before sign deployment (1996 and 1997) was compared to two years during sign deployment (1998 and 2000), using the non-parametric Mann-Whitney U test that tests for a shift in the center of the groups using rank sums. No difference was detected in numbers of DVCs in Algoma Township before and after sign deployment (Mann-Whitney U=25, chi-square approximation=1.26, df=1, p=0.26). This indicates that the signs had no effect on the numbers of DVCs occurring within Algoma Township. When the same two periods were compared for each of the other three townships separately, no differences between time periods were detected.

The effect of warning signs may have been masked by the overall variability in collisions occurring throughout Algoma Township. To examine the more targeted effect of novel warning signs, numbers of DVCs per stretch for the peak collision months of October, November, and December were examined. These data were extracted from the full data set using geo-processing to select DVCs occurring within 200 feet on either side of the treatment stretches and subsequently selecting data coded for October, November, and December. As in previous sign and reflector analyses, data from 1999 were excluded as an outlier (Figure 18).

Figure 18
Number of DVCs for Sign Deployment Period* By Year and Treatment Stretch Road

YEAR	STRETCHES						
	10 Mile	12 Mile	13 Mile	14 Mile	Algoma	North-land	Pine Island
1992	6	2	11	1	10	9	9
1993	17	6	19	2	18	6	10
1994	14	6	20	3	16	6	6
1995	23	4	7	3	19	8	9
1996	9	8	18	4	24	8	9
1997	16	2	9	3	22	11	11
1998	15	3	14	4	11	7	6
1999	10	0	17	0	15	0	0
2000	9	4	11	1	19	9	14
TOTAL	119	35	126	21	154	64	74

** Deployment period was during the peak DVC season of October, November, December.*

Lightly shaded boxes show years and township of sign deployment. Data from the outlier year, 1999, were not used in the analysis. Dark shading indicates the two years before sign installation that were used for comparison

Numbers of DVCs from a two year period before signs (1996 and 1997) were compared to a two year period after signs (1998 and 2000) across all treatment stretches using an r x c contingency table. Treatment stretches were independent of treatment period (χ^2=2.01, df=6, p=0.92). When all stretches were combined and compared across the two-periods, no difference was detected (χ^2=1.59, df=1, p=0.21). No effect of warning signs was detected on the number of DVCs occurring on the study stretches during the treatment period.

SPEED and TRAFFIC COUNTS

Speed

Data from the traffic counter deployed in 2000 were provided initially in a spread sheet format summarized by stretch, time, and traffic counts per 10 mile-per-hour speed category. This was expanded into a database format with each vehicle and its speed category recorded as a separate case to allow for the use of a t-test to compare mean speeds between the two time periods (before and after signs). Because this procedure of expanding a data set was very time-consuming, it was only performed for two stretches of road.

Algoma Road, speed records were selected for the same 15 hours before and after the signs were deployed in 2000 (1100 to 2400 hours and 0100). The data set included 1124 samples before signs and 1221 after signs. When a t-test was performed, averaging by time period), no difference in speed was detected (pooled variance, $t = -0.972$, $df=2343$, $p=0.331$).

For 10 Mile Road, the selected data set included records for a 24 hour period before and after signs were deployed in 2000. These showed a very small significant difference in speed (pooled variance, $t = -0.38$, $df=15563$, $p<0.0001$). This detected difference in means of less than 0.5 miles per hour, however, is likely far too small to have an effect on the probability of experiencing a deer-vehicle collision.

Traffic Counts and DVCs

By Time (Hour)

Traffic counts were significantly different across hours (Kruskal-Wallis test statistic = 81.75, df=23, p<0.0001) with the greatest numbers occurring during commuter hours (Figure 19). The numbers of DVCs were also significantly different across hours (Kruskal-Wallis test statistic= 63.50, df=24, p<0.0001) but with a evening/night peak that was later than the peak in traffic counts (Figure 20).

Figure 19
Traffic Counts by Hour

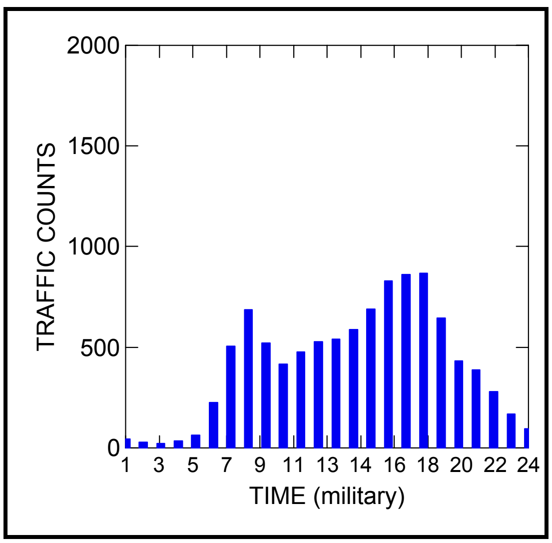
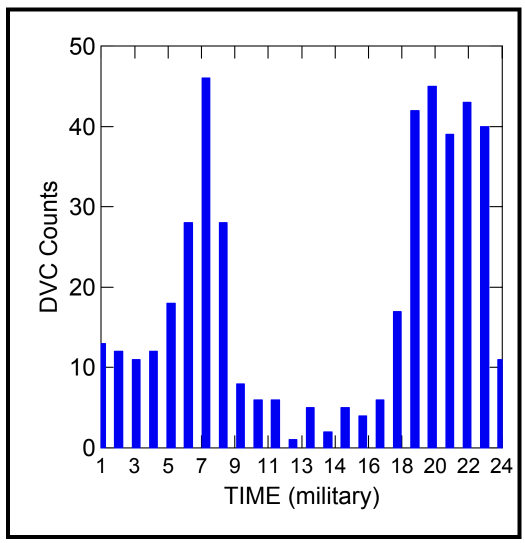


Figure 20
DVC Counts by Hour



A Spearman rank correlation between traffic counts and DVCs failed to show a relationship between the two variables when compared across hours for all 4 roads combined (Spearman rank correlation = -0.29). At the scale of the township, DVCs are not related to traffic volume.

By Road

At the scale of specific roads, there was a significant and perfect inverse relationship between traffic counts for the 24 hour periods from the 4 roads (Algoma, 10

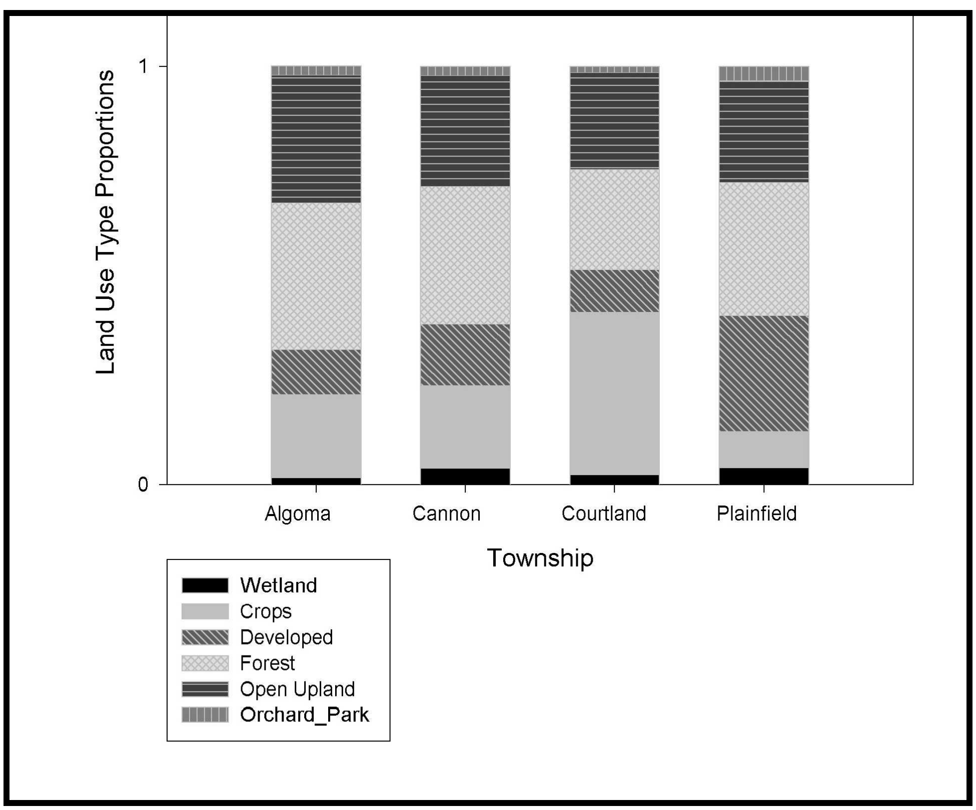
Mile, 13 Mile, and Northland) and the total number of DVCs cumulated over 9 years (Spearman rank correlation = - 1). When only the DVCs occurring in the sign test time period (1998-2000) were considered, a significant inverse relationship remained (Spearman rank correlation = -0.8). That is to say, the greater the numbers of DVCs on these stretches, the lower the traffic volume. This finding is converse to the relationship between traffic and DVCs at the scale of the township.

Spatial Patterns

Townships and Land Uses

A qualitative comparison of percentages of further consolidated land uses by township (Figure 21) showed similarity in land types among townships. The main differences appeared to be a larger proportion of cropland in Courtland Township and a greater percentage of developed land (commercial, industrial, and high density residential) in Plainfield Township. Cropland in Courtland accounted for nearly 40% of the total area. In Plainfield, cropland only occupied about 9% of the land base, with a greater percentage of developed land. The four townships also differed in the size of mapped cropland polygons (F=5.66, df=3, p=0.0009) with Courtland having larger sized cropland areas than Algoma and Plainfield Townships (Bonferroni adjustment, pairwise comparisons, 0.04 and 0.0006, respectively).

Figure 21
Proportions of Land Use Types by Township

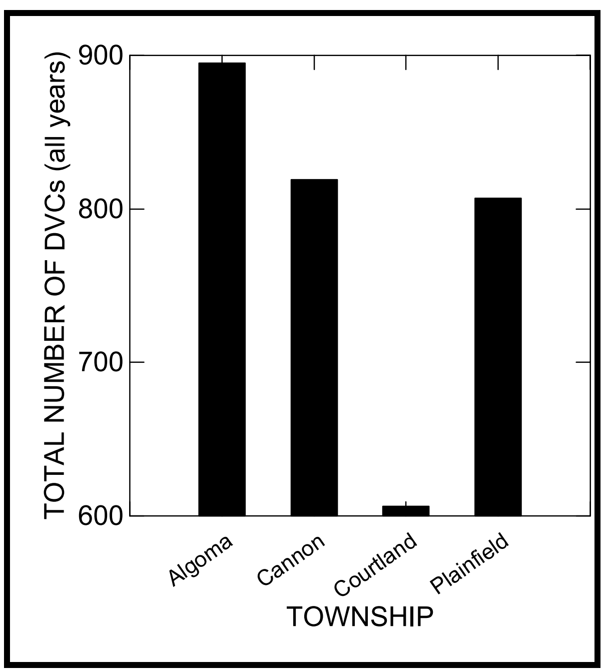


Townships significantly differed in their diversity as measured by the number of mapped land use polygons (χ^2=22.19, df=3, p<0.0001) with agricultural Courtland Township having the fewest polygons (882) and the more urban Plainfield having the greatest number (1068). A count of land use polygons may be considered to be one type of index of landscape patchiness or diversity.

Townships and DVCs

Townships were significantly different (at α = 0.10) from one another in average DVCs (tabulated by month and averaged across years) (ANOVA, 2.741, df=3, p=0.06). An examination of pairwise comparisons revealed this to be due to differences between Algoma and Courtland (Bonferroni adjustment, pairwise comparison, p=0.06). Figure 22 shows the raw counts of DVCs by year, by township.

FIGURE 22
Total Number of DVCs (all years)



Residuals from this analysis exhibited some heteroscedasticity, calling into question the use of a linear model. Therefore, this analysis was repeated using a non-parametric Kruskal-Wallis test. Once again, significant differences were detected among yearly numbers of DVCs tallied across months (Kruskal-Wallis test statistic=8.595, df=3, p=0.035). When Courtland Township was excluded from the data set, no difference remained (Kruskal-Wallis test statistic=1.210, df=2, p=0.546). Courtland had significantly fewer DVCs than the other townships.

Landscape

Logistic Regression Analysis

Sample grid cells were spatially joined to other line, point, and polygon shapefiles. Data from these shapefiles were then summarized by grid cell. Since only entire grid cells all of equal area were used, no summary data needed to be standardized by area. Number of DVCs were summed by grid cells. Number of landscape polygons were counted to give a measure of landscape patchiness or diversity. Using various combinations of geo-processing tools in ArcView 3.2®, landscape variables were constructed and summarized by the sample grid. The number of square feet in each land use category was calculated per grid cell with each value entered into the set as a variable. Lineal feet of roads and watercourses were also summed by grid cell.

Values of the sample grid variables were not normally distributed and did not have constant variances. This precluded the application of any linear models (such as linear regression or principal components analysis) to explore relationships between DVCs and landscape variables. Instead, the categorical multivariate general modeling module in SYSTAT 10® was used to develop a logistic regression model (LOGIT module). A logit transformation can be viewed as a means of linearizing the inherent nonlinear relationship between the independent variables and the probability of the dependent variable (Pampel 2000). Logistic regression treats the distribution in a probabilistic way, evaluating the occurrence of the dependent variable in terms of probability.

The dependent variable, DVC counts per sample grid cell, was given a binary code: "0" for no DVCs (reference condition) and "1" for presence of DVCs (response condition). Seventy-five percent of the sample grid squares had DVCs in them.

Two other binary-coded dependent variables that incorporated differing densities of DVCs were also tested (e.g. 0 to 6 = "0" and >7 = "1" and 0 to 16 = "0" and 17 to 37 = "1") but these variables produced very weak models and were not pursued further.

A randomly selected half of the whole sample (Sample A) was used to build a predictive model that could be validated using the other half of the data set (Sample B) (Figure 9). Initially, a full set of potential parameters, with land use types broken into fairly specific categories, was examined through correlation to eliminate inter-correlated variables. This was followed by stepwise logistic regression with similar land use categories combined further to eliminate missing data in cells. These new combined parameters (Figure 23) were then re-analyzed using stepwise logistic regression to identify a subset of parameters that were used to build a predictive logistic regression model (logit model).

Figure 23
Landscape Parameters Used in Stepwise Logistic Regression

VARIABLE NAME	DESCRIPTION
HWYRD	Linear feet of highways and roads
WTRCRS	Feet of watercourses (drains, streams, and rivers)
CRS_CT	Number of mapped culverts representing road crossing of watercourses
RIPARIAN_RD	Linear feet of roadway within 1000 feet of a watercourse
LU_POLYCT	Number of mapped land use polygons (an index of "patchiness")
HI_DEV	Square feet of high development (commercial, industrial, and high density housing)
MED_DEV	Square feet of crops, orchard, park, and low density residential
LO_DEV	Square feet of aquatic, forested, field, open wetlands, shrub land, and riparian land
STRT	Linear feet of residential streets

(Shaded cells represent parameters used to build LOGIT model)

A complete logistic regression model was then run using the shaded parameters in Figure 23 and the binary coded dependent variable, DVCCT. The T-ratio (ratio of coefficient to its standard error) for each estimated variables was examined to determine which variables were significant predictors of DVCCT. In addition, the confidence intervals for odds ratio for each variable were also examined to identify which variables had confidence intervals that were greater than 1. Variables found to be significant in predicting the probability of there being DVCs in a sample grid cell were LU_POLYCT (numbers of land use polygons), HWYRD (linear feet of highways and roads), and RIPARIAN_RD (feet of roadway within 1000 feet of a watercourse).

The LOGIT model statement was re-run using only these three parameters and data from Sample A to develop the following three variable predictive model:

PROB_DVCCT = -1.677199 + (0.079582*LU_POLYCT) + (0.000072*HWYRD) + (0.000252*RIPARIAN_RD)

According to the model, three independent variables help predict the presence of deer-vehicle collisions in a sample grid cell. These are: (1) the number of land use polygons (an index of landscape diversity), (2) the total feet of roadway, and (3) the total feet of roads falling within 1000 feet of a watercourse. The coefficients of these variables tell how much the logit model increases for a unit increase in an independent variable. The probability of a "0" or "1" outcome is a nonlinear outcome of the logit (SYSTAT 10ꝏ 2000).

For the purposes of this study, this model is useful as a means to determine which measured landscape variables are most important in determining whether or not DVCs occur in an area. As mentioned earlier, attempts to develop models that incorporated some measure of DVC density into the binary coding did not succeed, at least with the landscape variables that were available in this project.

An assessment of the model of the whole was obtained from calculating and comparing the likelihood ratio statistics (LR) (SYSTAT 10ꝏ 2000) for the baseline (constants only model) and the full model. Multiplying that difference by -2 produces a chi-squared value with degrees of freedom equal to the number of independent variables (Pampel 2000). The resulting statistic tests the null hypothesis that all coefficients except the constant are 0 (SYSTAT 10ꝏ 2000). For the Sample A data, this test produced a chi-squared test statistic of 81.56 with 3 degrees of freedom and a significant p value of <0.0001. This test indicates that there is reason to reject the null hypothesis that all variable coefficients equal 0.

Another way to examine the data is via McFadden's rho-squared statistic. This is a transformation of the LR statistic that mimics an R-squared of a linear regression model. It ranges between 0 and 1 with higher values corresponding to more significant results. The values are typically lower than R-squared with values between 0.20 and 0.40

considered to be very satisfactory (SYSTAT 10® 2000). For Sample A data, the McFadden rho-squared was 0.26, indicating a satisfactory fit of the model.

The predicted probabilities (lying between 0 and 1) from the model were saved in a file by using the regression diagnostic module. These were then coded as a new binary variable whose values were 1 for probability > =0.5 and 0 for probability <0.5. When the predictive power of the model was examined by doing a cross-tabulation of these new coded variables versus the observed binary values, the success rate was found to be 92% for the reference (1) cells.

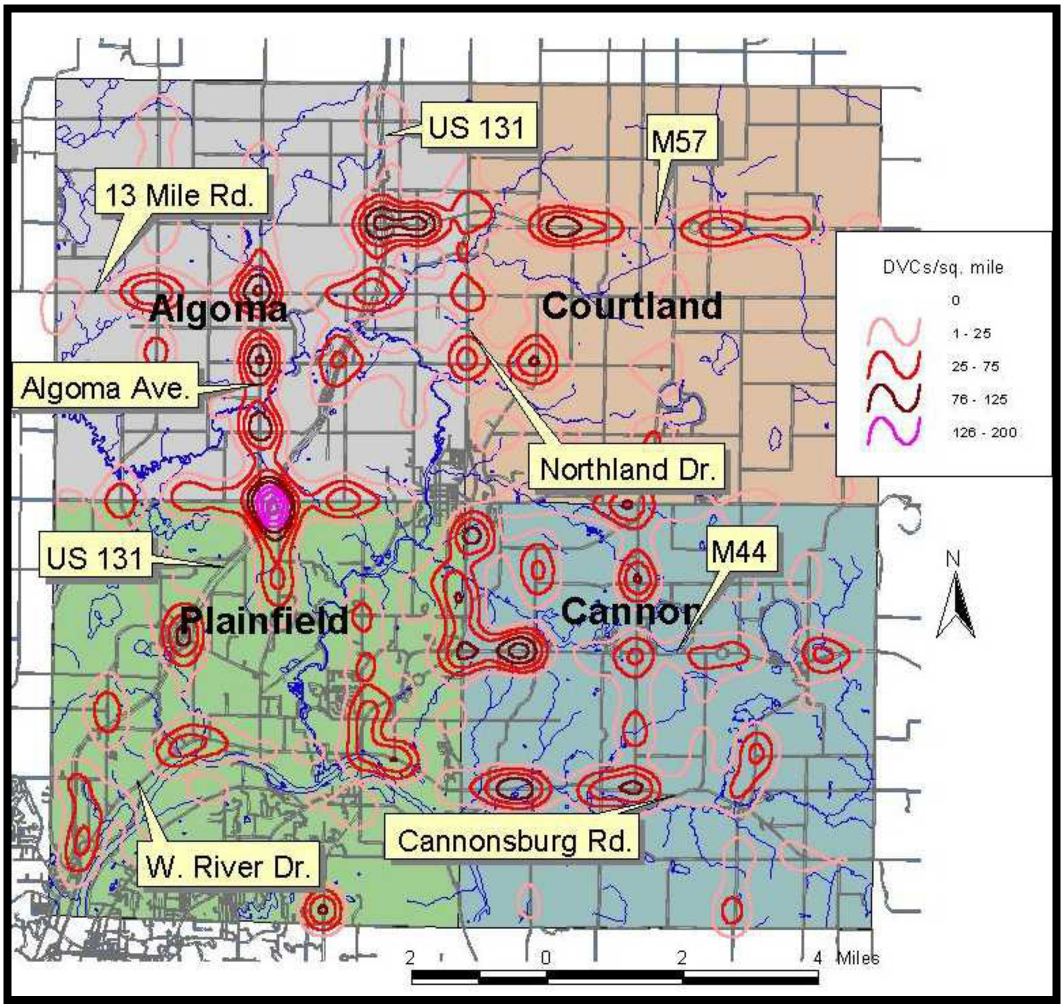
The model was then tested using validation data from Sample B by running commands in the BASIC module using the LCF (logistic cumulative function) procedure in SYSTAT 10® (Wilkinson et al. 1996). When the predictive power of the model was examined by assigning binary codes to the predicted probabilities, the model was found to correctly predict 96% of the reference (1) cells.

Visual Analysis

The density and contour mapping resulting from work in ArcView3.2® Spatial Analyst were examined to look for qualitative patterns of density of DVCs, superimposed over landscape features such as roads and rivers. The first mapping was of DVC densities summed across all 9 years. This visual display of high DVC density "hot spots" (high density DVC areas, mapped with contour lines) showed that major collision areas were located along the main arteries, with particular emphasis on the intersections (Figure 24). The occurrence of particularly intense hot spots at intersections may, in part, be due to the manner in which the location of accidents are recorded using intersections as points of reference and may not always reflect a concentration of DVCs in that precise location. Nevertheless, the greater cumulative number of vehicles at junctions of two major roads may truly contribute to higher cumulative totals of DVCs.

The highest density of accidents occurred at the US 131 Interchange 97 serving 10 Mile Road, Algoma Road, Belmont Road, with over 125 accidents per square mile cumulated over the 9 year study period (1992-2000). The US 131 Interchange 101 linking 131 and M57 was also a particular hot spot for DVCs as were several other interchanges. Roads with multiple hot spots included Algoma Road, West River Drive, Wolverine Drive, M44, M 57, Myers Lake Road, Cannonsburg Road, and 10 Mile Road.

Figure 24
DVC Hot Spots, 1992-2000

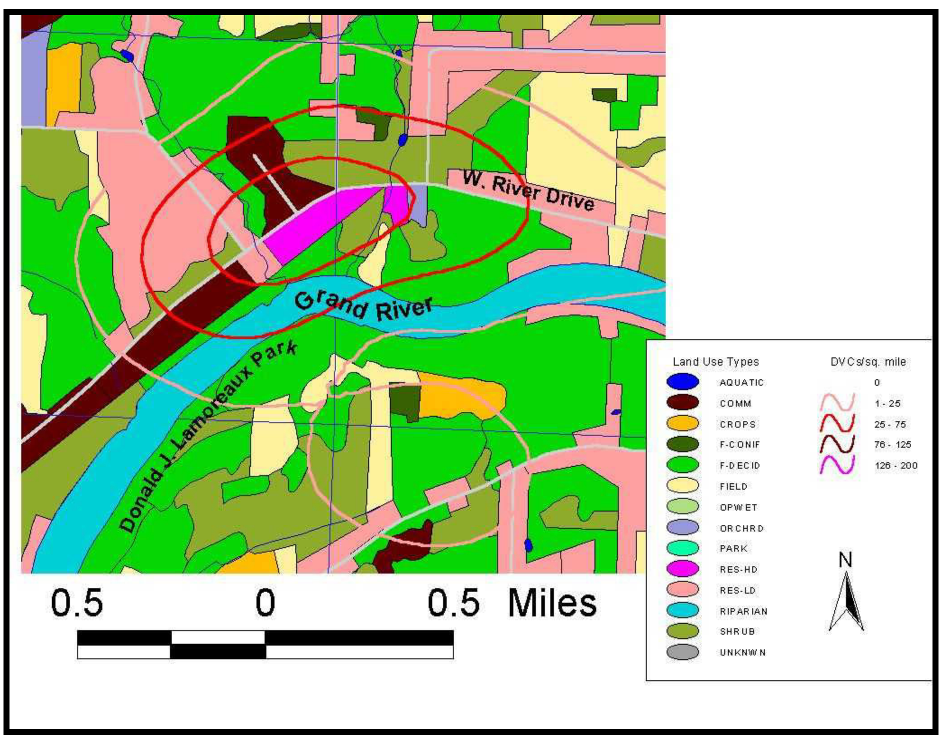


There may be contributing factors to DVCs at particular hot spots that don't reveal themselves in a statistical analysis. For example, the hot spot at the US 131 Interchange

97 may reflect the movement of high speed traffic into the lower speed two lane roads passing through deer habitat. The combination of many vehicles over time traveling at high speeds through good deer habitat may create this particular hot spot even though the data don't lend themselves to discernment of a hot spot by statistical analysis.

In other cases the juxtaposition of good deer habitat, deer movement corridors (such as riparian areas), and busy roads may sustain a hot spot. For example, West River Drive follows the Grand River, which likely increases the likelihood of DVCs occurring along a natural deer movement corridor (Figure 25). In addition, the immediate landscape around one particular hotspot shows a fair proportion of residences intermixed with wooded land and fields. Part of this wooded land is composed of a riparian park (Donald J. Lamoreaux Park) which may serve as a refuge for deer, which then disperse into the larger landscape or temporarily move out into the larger landscape in search of feeding opportunities (Hansen et al. 1997).

Figure 25
Close-up of a Riparian Hotspot
(red and pink contours denote high density DVC area)



There was very little change in the patterns of hot spots across the years. When hot spots were examined in three-year blocks, only minor shifts in location and density occurred (Figures 26, 27, and 28). Some of these shifts might be due to new development that displaced deer from their habitat and increased their mobility and vulnerability to collisions. Changes in deer movement might also result from shifts in food attractants, such as a change in cultivated crops, or commencement of feeding by human residents. This type of visual GIS analysis can be used in conjunction with local knowledge to identify new hot spots, with the information provided to the public.

Figure 26
DVC Hot Spots (1992, 1993, and 1994)

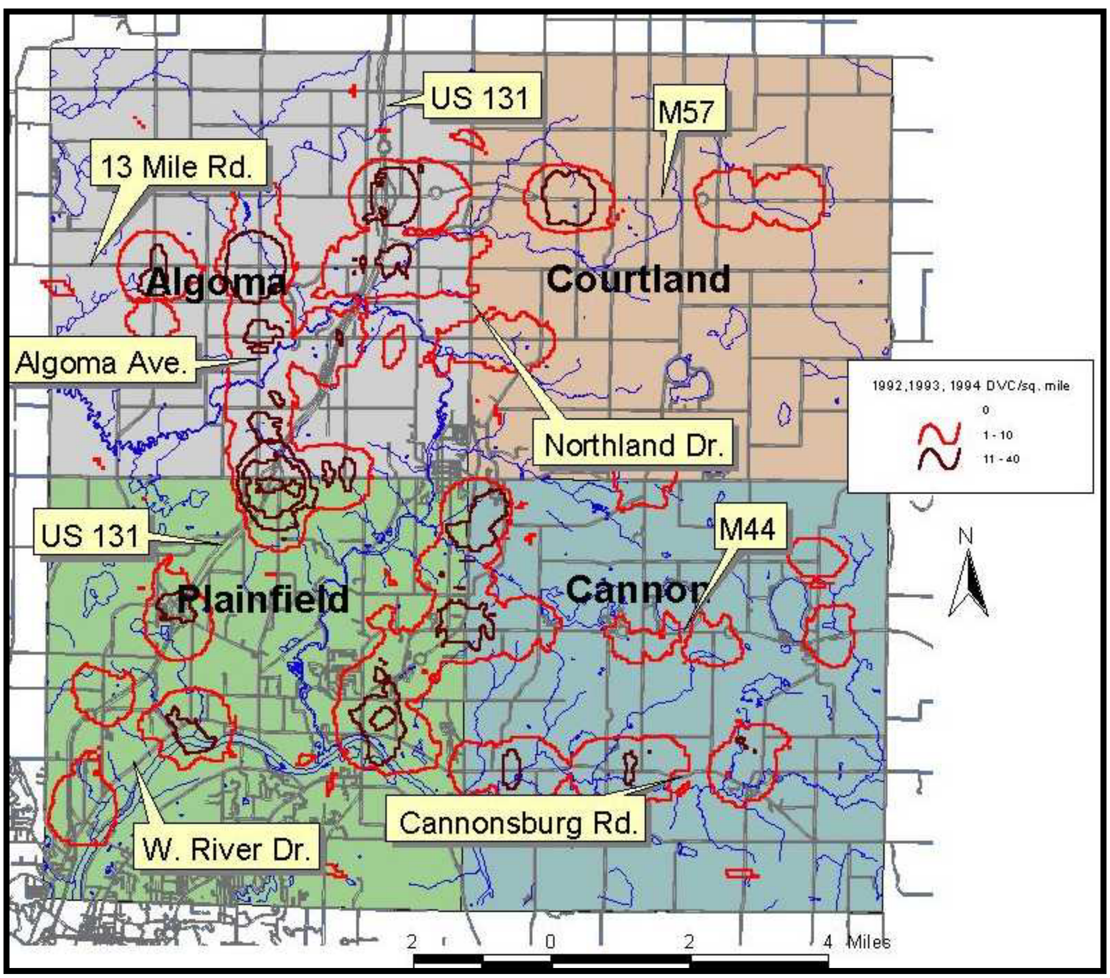


Figure 27
DVC Hot Spots (1995, 1996, and 1997)

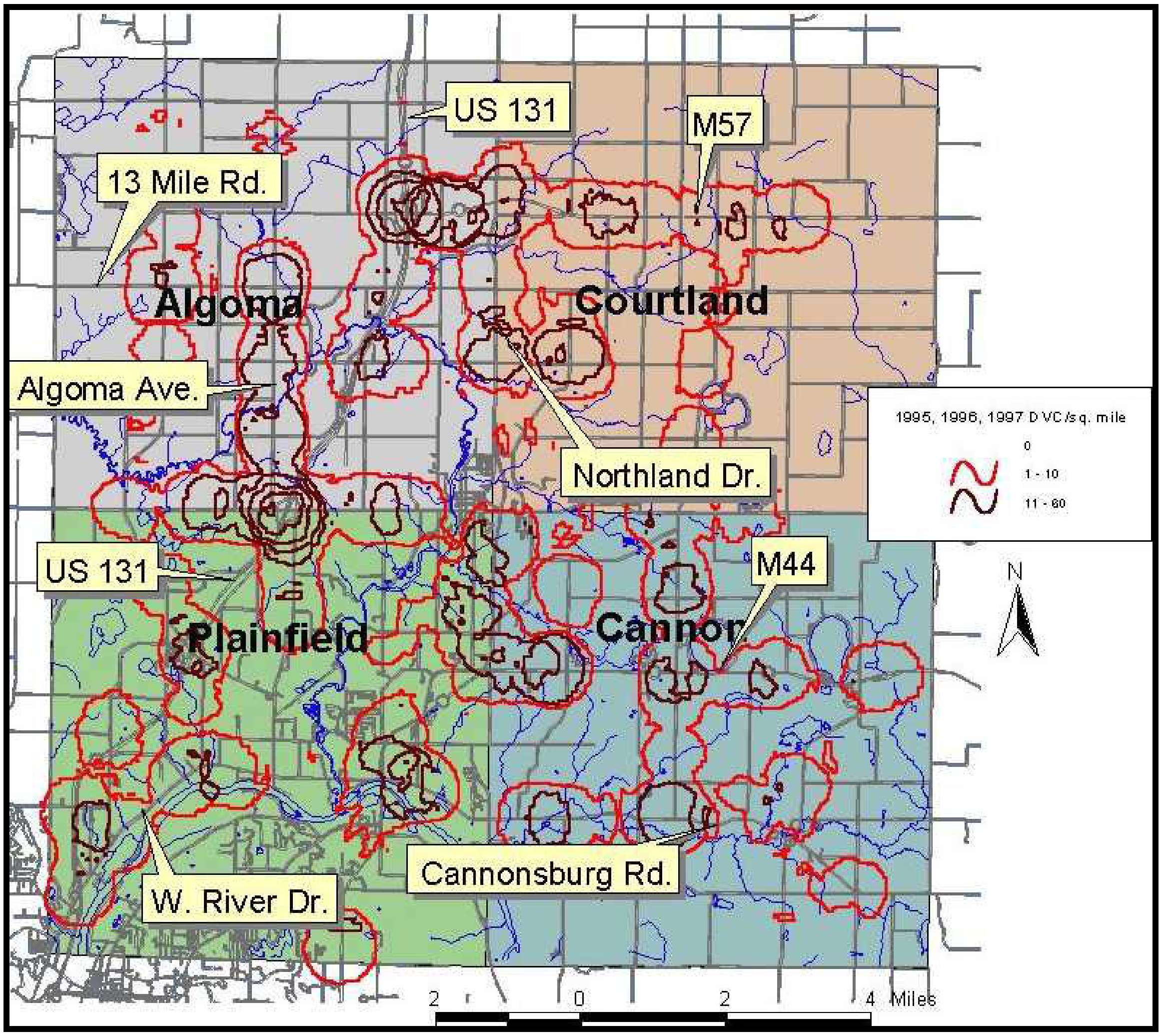
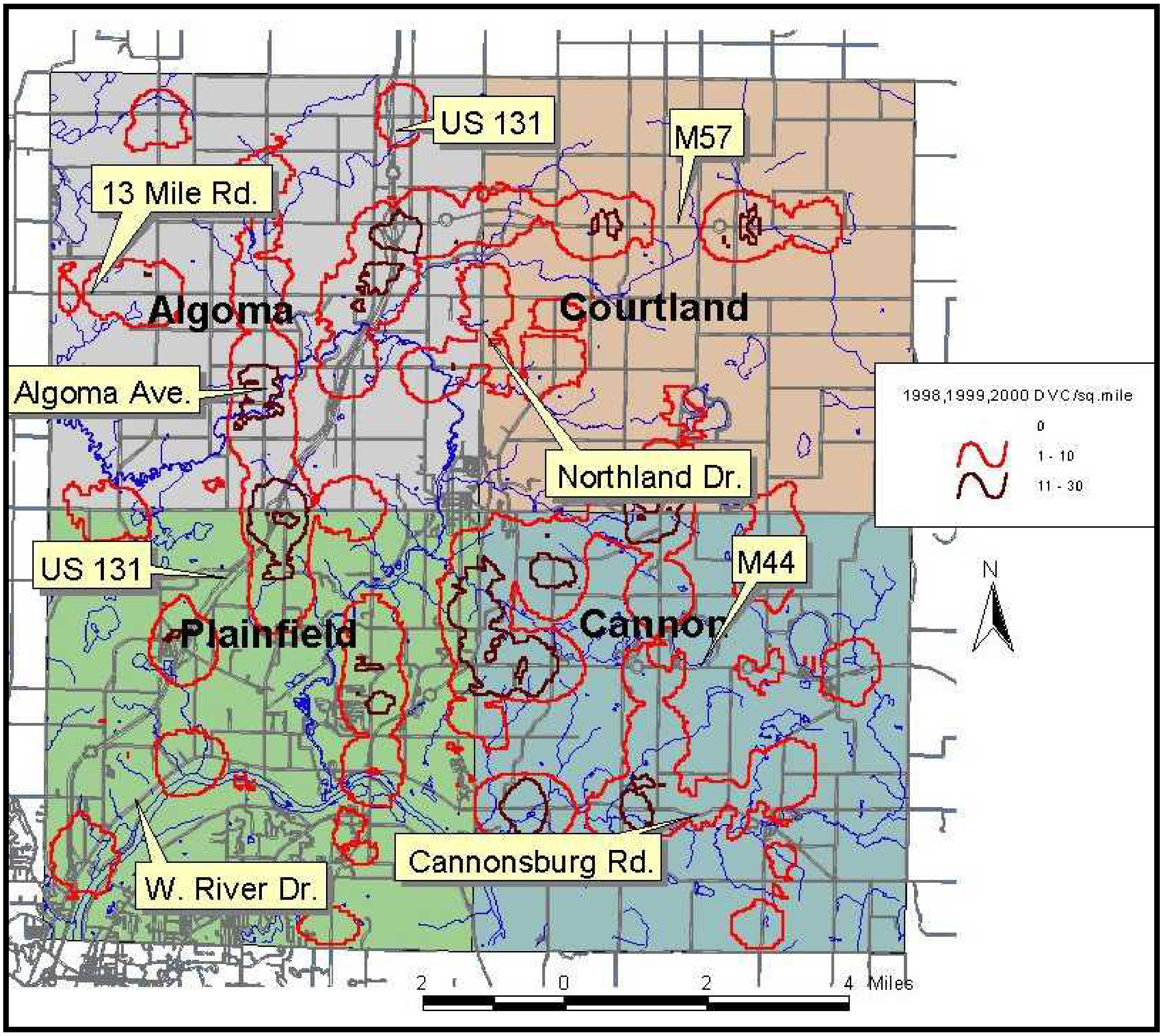


Figure 28

DVC Hot Spots (1998, 1999, and 2000)



SECTION V: DISCUSSION

Temporal Patterns of DVCs

There is high temporal variability in the occurrence of DVCs in the project area. Yearly DVC numbers appear unpredictable, although they may be correlated, at least in part, to fluctuations in local subpopulations of deer. Broader scale correlations between deer harvest levels and DVCs have been reported (McCaffery 1973). This relationship could be examined further if specific, local surveys of deer subpopulations were conducted in the future.

Such yearly variation makes it difficult to assess the efficacy of mitigative measures such as warning signs, fencing, and reflectors. This inherent variability of yearly numbers of DVCs makes a multi-year study imperative for testing effects of mitigative measures and, conversely, makes the results of any one year study suspect. The unusually low numbers of DVCs in 1999 in this study illustrates the analysis problems that can arise with small sample sizes and high yearly variation. The multiple years of this project made it possible to test the effects of warning signs and wildlife reflectors. In both tests, the null hypothesis of "no effect" was not rejected.

Seasonal variability is also high, but very predicable. The fall and early winter months of October, November, and December accounted for over half of all DVCs in the 9 year study period. November alone accounted for nearly a quarter (23.2%) of all DVCs of the project! There was no spring peak. In this study, January, May, and June were similar in their percentages of total DVCs. This is a similar pattern to that reported from 10 county study in southern Michigan (Allen and McCullough 1976).

There is likewise high variability in numbers of DVCs by time of day, but this is predictable with the greatest numbers occurring between 5 and 8 AM and 6 and 12 PM. There was a 5 hour period in the evening/night period (from 7 to 11 PM) that was particularly high in numbers of DVCs. This peak collision period extends more hours and later at night than the studies reporting only crepuscular (dawn and dusk) peaks.

To summarize, in any one year, the occurrence of DVCs is unpredictable.

However, the chances of having a DVC are much greater in the early morning or night in the fall to early winter season.

Landscape Patterns of DVCs

The project landscape is a patchwork of roads, streams, and land use types with many land uses that provide acceptable to good deer habitat. The patchwork nature of the landscape appeared to be an important factor in creating good conditions for DVCs. The logistic regression model included number of land use polygons as an important predictive variable, supporting this conclusion. In addition, the township with the lowest 9 year count of DVCs, Courtland Township, also had the lowest numbers of mapped land use polygons and the largest areas of cropland. This further suggests that landscapes with a greater patchiness of land types, particularly those providing suitable deer habitat, are more prone to producing deer-vehicle collisions than those with larger intact blocks of vegetative types. Landscape diversity has been correlated with higher DVC counts in a study in Illinois (Finder et al. 1999). In this study, in cropland-dominated Courtland Township, deer may be able to find food and cover on the more extensive blocks of cropland without having to move as frequently and cross as many roads, thus lowering the overall risk of vehicle collisions. A landscape DVC study in Iowa also concluded that areas with large crop fields decreased the probability of deer-vehicle collisions (Hubbard et al. 2000). Results from an Illinois study also concluded that row crops provided low values as deer forage habitat and less of an attractant (Roseberry and Woolf, 1998). Several studies indicate that more DVCs occur near the edge of woods (Finder et al. 1999, Puglisi et al. 1974). These studies, however, come from landscapes where wooded land is a rare feature and not so intermixed with other vegetative types as the project landscape. On the project landscape, it may be that most locations are sufficiently near wooded cover (shrubs and trees) to negate the influence of this vegetative feature on the location of DVCs. Conversely, research in primarily wooded landscapes has demonstrated the attractiveness of highway rights-of-way as feeding areas. This is an effect not seen as dramatically in predominantly agricultural landscapes (Carbaugh et al. 1975), such as the project area. Along the same lines, low seasonal movement of female deer has been reported from suburban environments that are apparently diverse enough within themselves to accommodate the habitat needs of deer (DeNicola et al. 2000).

The significant variables in the logistic regression model further substantiate landscape patchiness (in this study measured in numbers of polygons and cumulative length of roads) as important in increasing the probability of deer-vehicle collisions. A habitat suitability study from an agricultural landscape in Illinois reported a positive association between deer populations and moderate forest fragmentation (Roseberry and Woolf 1998). At the scale of a county, miles of road do not necessarily correlate with number of DVCs. When the numbers of DVCs for 1999 were directly compared to the miles of road for the ten Michigan counties (Kent, Jackson, Calhoun, Oakland, Montcalm, Mecosta, Menominee, Eaton, Ingham, and Kalamazoo, data from Sudharsan and Streff 2001) that were highest in numbers of DVCs, no significant relationship was found (Spearman rank correlation 0.41). It appears to make a difference at what scale landscape data and DVCs are examined. The size of the project area and the scale at which landscape variables are measured should be taken into account when comparing any studies on DVCs.

Roads near watercourses also increase the probability of DVCs occurring. The use of riparian areas as animal movement corridors is well known (NRC 2002). Other DVC studies have reported the presence of bridges to be a significant landscape variable that predicts locations that are prone to DVCs, most likely because of their association with riparian corridors (Finder et al. 1999, Hubbard et al. 2000).

Reflectors and Warning Signs

None of the mitigative techniques in this project produced any measurable reduction of numbers of deer-vehicle collisions. There were no detectable effects of the wildlife reflectors or the warning signs on the numbers of DVCs in the test stretches. The potential problems presented by variability in DVCs among years are dramatically illustrated by the low DVC counts for the test and control stretches in 1999. By chance, no collisions occurred in the experimental stretches in that year. Had there not been data on the larger landscape that helped identify 1999 as an outlier year, or had there only been one year of experimental data, erroneous conclusions could easily have been drawn with respect to the effectiveness of the reflectors and signs. The multi-year nature of this study and the inclusion of untreated townships helped avoid these pitfalls.

A study of the effect of reflectors on mule deer in Wyoming also failed to show a reduction in DVCs (Reeve and Anderson 1993). Successful reduction of collisions was reported from a very small (n=4) study in Washington (Schafer and Penland 1985). By contrast, in a controlled enclosure study, Zacks (1985) reported no evidence that deer responded to light from the reflectors and suggested that where reflectors seem to work that they may have influenced the behavior of the drivers rather than the deer. In a potentially related study using red laser lights, no effect was found on deer dispersal and the researchers questioned whether deer can physiologically see red light (VerCauteren et al. 2003). Research continues on the spectrometric properties of the reflectors and the perceptive abilities of deer (British Columbia Ministry of Transportation and Highways 2001). There may also be differences, as yet unmeasured, in the efficacy of the reflectors in some landscapes, taking into account factors such as vegetation and topography and defined animal movement corridors. This current study is small in scope and is by no means a definitive finding on the efficacy of reflectors under all conditions.

Although a small reduction in speed of less than 0.5 miles per hour was detected on one of the warning sign test roads, it was likely far too small to result in a decrease in DVCs and no reduction in collisions was detected. In order to produce a meaningful decrease in speed, warning signs would probably have to be coupled with law enforcement efforts. A study in Colorado reported a reduction in speed of about 3 miles per hour in the presence of warning signs (Pojar et al. 1975), also likely to be too small to produce detectable decreases in DVCs.

To further complicate the analysis and ideas about prospective solutions, the relationship between traffic and DVCs was not clearcut. The peaks in DVCs by hour in this project decidedly do not correspond to the traffic peaks. This suggests that occurrences of DVCs are more closely tied to peak deer movement periods than to peak periods of vehicle movement. Another counterintuitive finding was the inverse correlation between 24 hour traffic counts and the 9 year cumulative DVC counts on four roads. From our limited sample of four roads, it appears that the highest traffic volume roads are not as conducive to deer movement as relatively lower traffic volume roads.

The frequent and high speed traffic itself may present a barrier (Bashore et al. 1985), or the immediate landscape of the road may be less attractive to deer, or both. A more detailed examination of specific stretches of roads, their traffic counts, DVCs, and immediate road landscapes might be able to tease apart patterns at this more specific level. Based on these preliminary findings, one would hypothesize that a larger data set might show low DVCs on very low traffic roads, high DVCs on the medium to high traffic count roads, and lower DVCs on the very high traffic volume roads. Unfortunately, the project landscape has numerous roads that fall into the intermediate category of medium to fairly high traffic volume, that also pass through a rural patchwork landscape, likely increasing the risk of DVCs. Finally, although vehicle speed is likely a factor, it is questionable that speed could be reduced enough to reduce the occurrence of DVCs.

A periodic mapping of DVC hot spots using a density function in ArcView 3.2® could be used to identify very specific sites for deer management activities. For example, they might indicate locations for deployment of fencing relative to deer forage and cover (Falk et al. 1978, Feldhamer et al. 1986) and variations in topography (Bellis and Graves 1971), as well as locations for deployment of seasonal warning signs or enforced seasonal speed reduction zones. This would likely do little to reduce DVCs over the larger landscape, but might mitigate very specific problem areas. An example of such a location might be a natural park adjacent to a moderately busy road.

Mapped hot spots might also be used to specifically identify locations for hunting or professional lethal deer control. Research on home ranges of deer has shown that female home ranges expand as deer generations expand, with each female sharing a home range with her female offspring, and with subsequent generations occupying partially overlapping home ranges. This pattern means that targeted lethal control may alleviate a DVC problem for a period of years until generations of female deer have once again filled the available space (McNulty et al. 1997, Porter et al. 1991). If applied in this specific way, lethal control is more cost effective solution, has less overall impact, and potentially less negative public reaction.

To increase future understanding of DVC patterns, additional thematic layers could be added to the Kent County geographical information system. It would be useful to be able to view patches of undeveloped green space such as parks, nature reserves, and open public land relative to occurrence of DVCs. Some of these areas may serve as refuges for the deer population and helpful predictors of where DVCs occur. In addition, should professional lethal control become necessary, these patches might serve as the likeliest locations for that activity. If deer censusing occurs in the county, these data could also be added to the GIS project.

Driver Education and Public Awareness

Although it is difficult to measure the success of an educational campaign to alert drivers to the DVC hazard, a risk awareness program should likely be continued, targeting both the student driver level as well as the overall driving population. The driver education teachers were the most enthusiastic about the concise facts that were provided them, such as the facts about the high numbers of DVCs in Kent County. That local knowledge seemed to make the biggest impression on the students.

Driver education campaigns should also incorporate information about the spatial and temporal likelihood of occurrence of DVCs gained from this and similar studies. The logistic regression analysis showed that probability of having an accident increases in a very fragmented landscape, such as typifies the residential sprawl into former farmland north of the City of Grand Rapids. This information may be counter to what most people think. Many drivers may assume that the highest probability of having a collision with a deer lies in a landscape that is predominately rural with large fields or woodlands. They may be unaware of the higher risk they face in a daily commute to the city from rural residences through a landscape of fragmented deer habitat. Once in landscapes that are predominantly developed, the risk of DVCs likely drops again as there is less habitat to harbor deer. This drop in DVCs in predominately developed landscapes was not a quantitative result from this study. This result may be due to the deliberate selection of project townships that were similar in their mixture of agriculture and development. A contrasting study that also included more urban townships as well as more rural townships might produce a different sort of model than the one produced by this study.

Driver education should also include information about deer behavior. Urban drivers are often unaware of basic aspects of deer behavior, such as the species' tendency to travel in groups or use riparian areas as movement corridors. If deer population data become available and are positively correlated with numbers of DVCs, a public awareness program can also help build support for application of deer population reduction methods should they become necessary (Stout et al. 1993) or identification of areas for enforced speed reduction (Decker and Gavin 1987, Stout et al. 1993, Stout et al. 1997). Information on DVC hazards could be expanded in a public awareness program that educates the public on the negative impacts of an overly large deer population on the ecosystems of parks and the larger natural landscape, including negative impacts on songbirds and game animals (Augustine and Frelich 1998, Diamond 1992, Kilpatrick and Walter 1997, Tilghman 1989).

To summarize, driver education and public awareness campaigns should focus on creating an awareness on the high numbers of DVCs, the landscape features that increase individual driver risk (e.g. fragmented habitat, riparian corridors, medium to high volume traffic on suburban to rural roads), and deer behavior.

SECTION VI: CONCLUSIONS

The landscape mosaic of the four project townships in Kent County, Michigan provides ideal conditions for the occurrence of DVCs. The agricultural and open land serve as deer habitat. Riparian areas provide deer movement corridors. Humans continue to encroach into the rural landscape with new residences and commute through it on numerous two-lane roads. Given the mixture of deer habitat, movement of deer between habitat patches and movement of people (commuters), high rates of DVCs are likely to continue.

Analysis of landscape patterns in this project has shown that the probability of experiencing a deer-vehicle collision is higher on roads that pass near watercourses and roads that traverse patchworks of many land use types. Risk of DVCs is lower in areas with large intact blocks of land suitable as deer habitat. Temporal analysis revealed the same fall/early winter peak in numbers of DVCs reported in other studies. During the 24 hour day, drivers face the greatest risk of collisions in early morning and evening to midnight. It is unknown if the extended hours of high DVC risk into the night result from patterns of urban deer movement, people movement, or both. Deer movement behavior may differ in an urban to suburban landscape compared to a primarily rural landscape. All these types of information can be used in public awareness and driver education campaigns.

In this study, neither the warning signs nor the wildlife reflectors showed any effect of reducing DVCs. There may be situations where these techniques can be effective, but in this landscape matrix, the results were not promising and certainly not cost effective.

Research continues in other urban areas of the country on the effect of targeted lethal control in reducing DVCs. Often other factors, such as negative impacts on natural ecosystems of public lands, damage to agricultural crops or lawn plantings, or wildlife diseases or wildlife-borne diseases are additional precipitating factors leading to a decision favoring lethal control. Should lethal control become desirable in this county, the most cost-effective approach is probably targeting specific problem areas. Mapping, using geographical information systems, can be used to assist in the identification of such target areas.

The county geographical information system can continue to provide a good basis for future management decisions if kept up-to-date. Additional layers that might be considered for inclusion are natural areas and parks, areas of current or projected development, and spatially-specific deer population counts. The GIS could also be used to log locations of complaints about deer damage, agricultural or residential, to assist in identifying patterns of deer problems. Although there is currently no "silver bullet" to solve the DVC problem, the spatial and temporal data that were part of this study are invaluable tools for deciding future management actions.

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